AD-A146 358 STATISTICAL ANALYSIS OF VISUAL WAVE OBSERVATIONS AND GAGE/RADAR MEASUREMENTS(U) COASTAL ENGINEERING RESEARCH CENTER VICKSBURG MS M PERLIN JUL 84 CERC-MP-84-6 1/1

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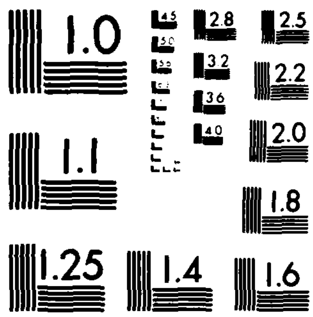
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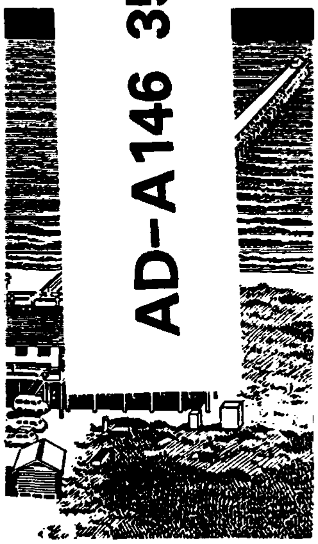

MISCELLANEOUS PAPER CERC-84-6 2

STATISTICAL ANALYSIS OF VISUAL WAVE OBSERVATIONS AND GAGE/RADAR MEASUREMENTS

by

Marc Perlin

Coastal Engineering Research Center

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July 1984

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for

DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper CERC-84-6	2. GOVT ACCESSION NO. AD-A146358	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) STATISTICAL ANALYSIS OF VISUAL WAVE OBSERVATIONS AND GAGE/RADAR MEASUREMENTS		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Marc Perlin		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Engineer Waterways Experiment Station Coastal Engineering Research Center PO Box 631, Vicksburg, Mississippi 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS DEPARTMENT OF THE ARMY US Army Corps of Engineers Washington, DC 20314		12. REPORT DATE July 1984 13. NUMBER OF PAGES 49
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Water waves--Measurement (LC)
Water waves--Observations (LC)
Oceanography--Statistical methods (LC)
Analysis of variance (LC)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents results of a study conducted to determine the variability of observations made simultaneously by several different observers, to compare those observations with instrument measurements when available, and to look at the temporal variation of observed littoral conditions over a 25-hour period. Littoral Environment Observations (LEO) taken by individual observers were compared with the means of the observations obtained by all

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20. ABSTRACT (Concluded)

observers and with instrument-recorded data when available for a particular variable.

Statistical analyses were performed for the different LEO variables to determine the following:

a. Confidence intervals.

b. Correlation coefficients.

c. Standard deviations.

d. Consistency between observer and gage.

e. Effect of tides on estimation of parameters (i.e., did the estimates depend on the distance between observer and waves?)

f. The statistical wave height to which LEO wave heights should be compared.

The field experiment was conducted at Duck, North Carolina, at the Field Research Facility (FRF) of the Coastal Engineering Research Center on 15-16 August 1978. Six observers simultaneously recorded hourly LEO observations. Concurrent wave measurements were made from the FRF pier with gages and radar.

PREFACE

This report presents the results of a study conducted by the Coastal Engineering Research Center (CERC) under the Littoral Data Collection Methods and Engineering Applications work unit of the Shore Protection and Restoration Research Program. Marc Perlin, formerly of CERC, currently at the Coastal and Oceanographic Engineering Department, University of Florida, prepared the report under the general guidance of Dr. J. Richard Weggel, former Chief, Coastal Structures and Evaluation Branch (CSEB), Mr. N. E. Parker, former Chief, Engineering Development Division, and Dr. R. W. Whalin, Chief, CERC. Dr. J. R. Weggel, Dr. T. L. Walton, and Dr. E. Thompson, CERC, reviewed the report. CERC was relocated to the U. S. Army Engineer Waterways Experiment Station (WES) in July 1983.

Commander and Director of WES upon publication of this report was COL Tilford C. Creel, CE; Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, INCH-POUND TO METRIC (SI) UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
miles (U. S. statute)	1.609347	kilometers
feet	0.3048	meters

STATISTICAL ANALYSIS OF VISUAL WAVE OBSERVATIONS AND GAGE/RADAR MEASUREMENTS

PART I: INTRODUCTION

1. The Littoral Environment Observation (LEO) program was established in 1968 by the Coastal Engineering Research Center (CERC) to obtain nearshore wave, wind, and current climatological data at specific coastal sites. The program is discussed in some detail by Berg (1969), Szuwalski (1970), Bruno and Hiipakka (1973), Balsillie (1975), and Schneider (1977). As part of the program, relatively inexpensive equipment is used by an observer to visually estimate or measure several variables applicable to coastal engineering problems. Variables measured include wave period, wave height, wave angle at breaking, wave type, wind speed (using a handheld anemometer), wind direction, foreshore slope (using a clinometer), width of surf zone, longshore current velocity (by pacing off the distance travelled by a dye packet), and the presence and spacing of rip currents and beach cusps. These data have been used to predict longshore transport rates, to verify models for other coastal phenomena such as beach cusp spacing, and to establish general wave and wind climatologies.

2. The present study was conducted to determine the variability of observations made simultaneously by several different observers, to compare those observations with instrument measurements when available, and to look at the temporal variation of observed littoral conditions over a 25-hour period. LEO observations taken by individual observers were compared with the means of the observations obtained by all observers and with instrument-recorded data when available for a particular variable. Statistical analyses were performed for the different LEO parameters to determine the following:

- a. Confidence intervals.
- b. Correlation coefficients.
- c. Standard deviations.
- d. Consistency between observer and gage.
- e. Effects of tides on estimation of parameters (i.e., did the estimates depend on the distance between observer and waves?)
- f. The statistical wave height to which LEO wave heights appear to correspond.

3. The field experiment described herein was conducted at CERC's Field Research Facility (FRF) at Duck, North Carolina, on 15-16 August 1978. Six observers simultaneously recorded hourly LEO observations. Concurrent wave measurements were made from the FRF pier with gages and radar.

PART II: THE FIELD EXPERIMENT

4. The FRF at Duck, North Carolina, shown in Figure 1 was the site of the field experiment. Six observers recruited from the CERC staff were stationed 725 ft* north of the pier (Figure 2). To simulate the variability of experience embodied in personnel who typically take LEO measurements in the field, individuals participating in the experiment included one experienced observer and two completely inexperienced observers. All individuals were exposed to the training session given to typical field observers.

5. Hourly observations of all LEO variables were made by each observer during a 25-hour period (26 observations) (the standard LEO form is shown in Figures 3 and 4). Observers were instructed not to discuss their observations during the experiment; each observer is therefore believed to have provided an essentially independent observation, unbiased by the observations of the others. The experiment's duration included two tidal periods to introduce a variable distance between the breaking waves and the observer and to evaluate this effect on the observers' estimates. Because of profile conditions, the surf zone at high tide for a given wave height was relatively narrow due to the steepness of the beach slope. For an equivalent wave condition at low tide, the surf zone was wider.

6. At the same time the visual observations were taken, Baylor gages on the FRF pier measured wave heights and land-based X-Band radar (Figure 2) provided screen images of the sea surface which were then photographed. For descriptions of the radar and wave gages, see Mattie and Harris (1979) and Thompson (1977), respectively.

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* A table for converting the inch-pound units of measure used in this report to metric (SI) units is found on page 4.

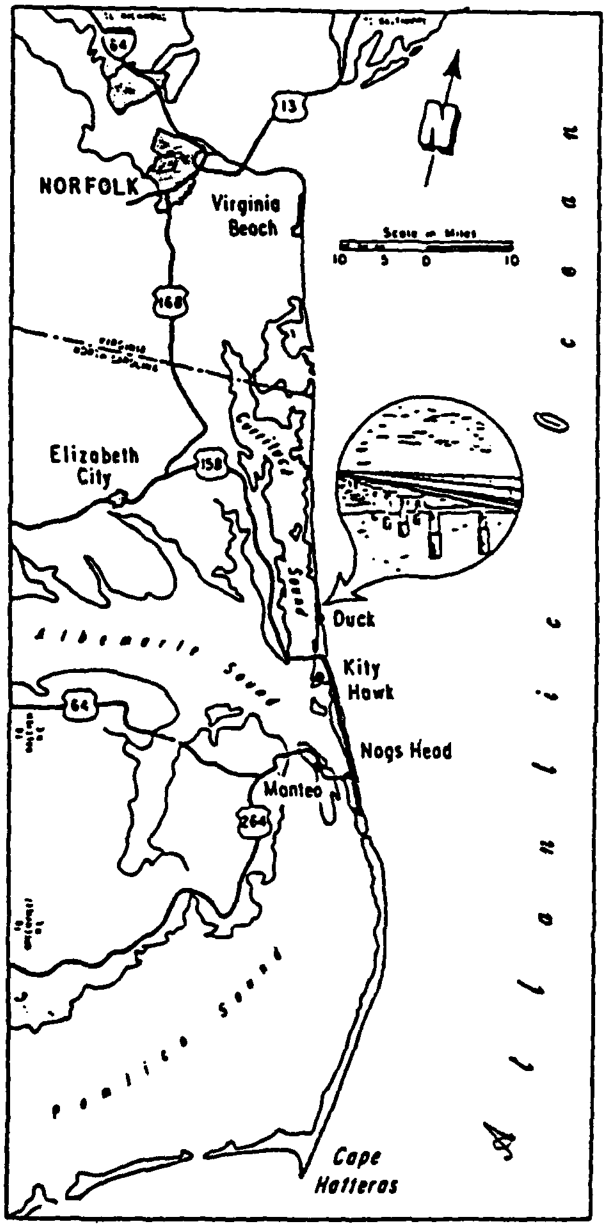
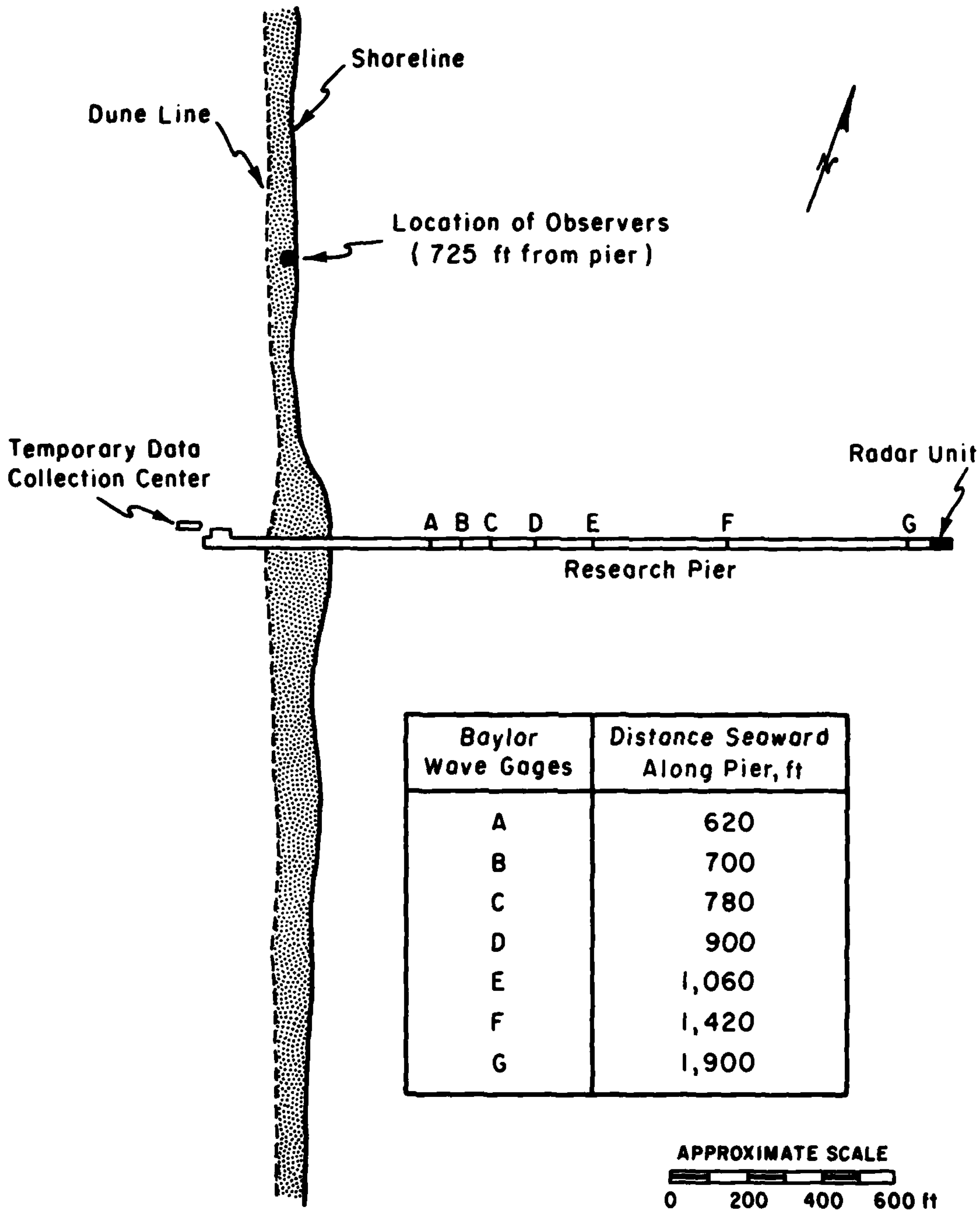


Figure 1. Location map for the Field Research Facility at Duck, North Carolina



Baylor Wave Gages	Distance Seaward Along Pier, ft
A	620
B	700
C	780
D	900
E	1,060
F	1,420
G	1,900

Figure 2. Observers and gage locations during the experiment

LITTORAL ENVIRONMENT OBSERVATIONS

RECORD ALL DATA CAREFULLY AND LEGIBLY

SITE NUMBERS 1 2 3 4 5 | **YEAR** 6 7 | **MONTH** 8 9 | **DAY** 10 11 | **TIME** Record time using the 24 hour system 12 13 14 15

WAVE PERIOD (16 17 18)
Record the time in seconds for eleven (11) wave crests to pass a stationary point. If calm record 0.

BREAKER HEIGHT (19 20 . 21)
Record the best estimate of the average wave height to the nearest tenth of a foot

WAVE ANGLE AT BREAKER (22 23 24)
Record to the nearest degree the direction the waves are coming from using the protractor on the reverse side. 0 if calm.

WAVE TYPE (25)
0 – Calm
1 – Spilling
2 – Plunging
3 – Surging
4 – Spill / Plunge

WIND SPEED (26 27)
Record wind speed to the nearest mph. If calm record 0

WIND DIRECTION – Direction the wind is coming from (28)
1-N 3-E 5-S 7-W 0-Calm
2-NE 4-SE 6-SW 8-NW

FORESHORE SLOPE (29 30)
Record foreshore slope to the nearest degree.

WIDTH OF SURF ZONE (31 32 33 34)
Estimate in feet the distance from shore to breakers, if calm record 0.

LONGSHORE CURRENT

DYE (36 37 38)
Estimate distance in feet from shoreline to point of dye injection.

CURRENT SPEED (43 44 45)
Measure in feet the distance the dye patch is observed to move during a one (1) minute period; If no longshore movement record 0.

CURRENT DIRECTION (46 47)
0 No longshore movement
+1 Dye moves toward right
−1 Dye moves toward left

RIP CURRENTS (49 50 51 52)
If rip currents are present, indicate spacing (feet). If spacing is irregular estimate average spacing. If no rips record 0.

BEACH CUSPS (54 55 56)
If cusps are present, indicate spacing (feet). If spacing is irregular estimate average spacing. If no cusps record 0.

PLEASE PRINT:

SITE NAME ____________ OBSERVER ____________

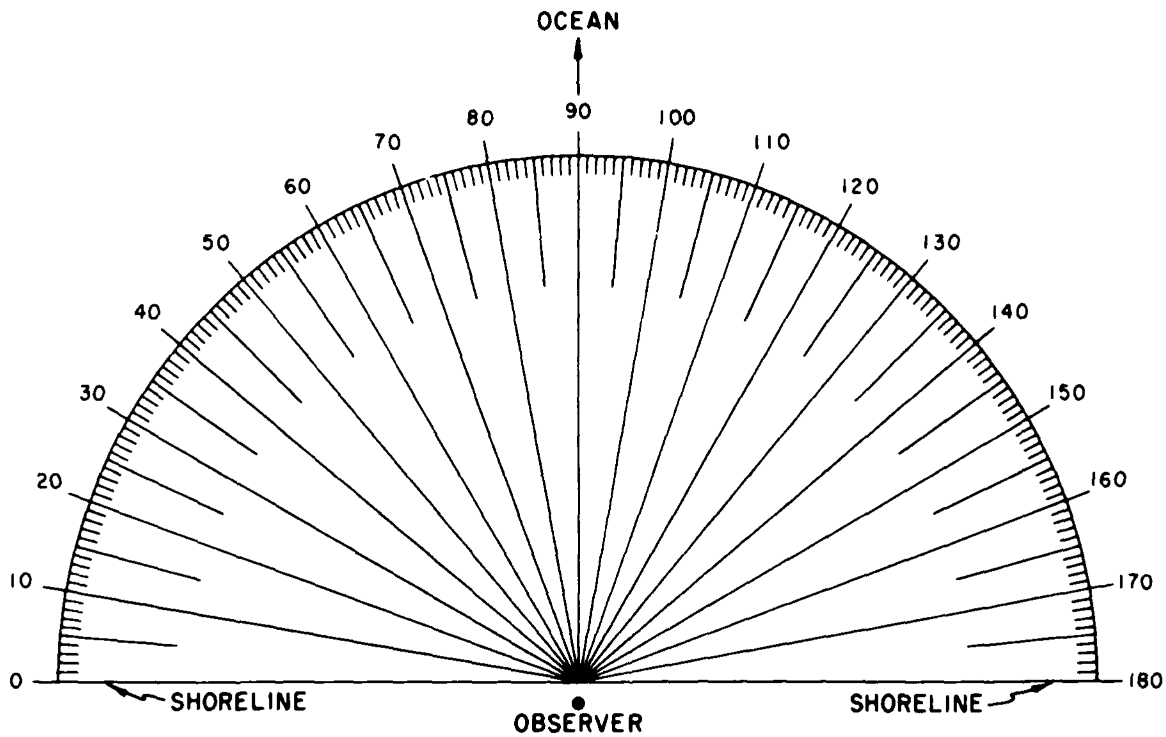
Please Check The Form For Completeness

REMARKS: ____________

CERC 113-72
8 Mar 72

Make any additional remarks, computations or sketches on the reverse side of this form.

Figure 3. Front of standard LEO form, used to record data



NOTE: If a pier is used for an observation platform: place 0-180 line on the rail parallel to the centerline of the pier, site along the crest of the breaking waves and record the angle observed.

Figure 4. Back of standard LEO form, used to obtain wave angle

PART III: DATA COLLECTION AND TRANSFORMATION

7. A description of the visual and measured data is presented below. No rip currents or beach cusps were observed during the experiment; hence, no further discussion of them is included herein.

Wave Heights and Periods

8. Twenty-minute wave gage records of the sea surface were analyzed to determine significant wave heights and periods. Data from each gage were recorded at the rate of four points per second for a 20-minute duration, and the record, composed of 4096 data points, was analysed using the standard CERC computer analysis. In this analysis, the first step is to edit the data for non-numeric characters or anomalous spikes. Usually, highly questionable points are rejected and the record supplemented by interpolation. If more than 2.5 percent of the points are deemed bad, the routine rejects the record as unsuitable for analysis. For acceptable records the distribution function and its first five moments are computed and a data window applied to the data points--this technique produces greater resolution of the frequency spectrum of the record. The program then computes the variance spectrum. Significant wave height is obtained as four times the standard deviation of the record. Significant wave period is defined as the reciprocal of the frequency at the middle of the spectral band with maximum energy; when two wave trains occur, the significant wave period is taken as the one associated with the larger energy peak. For a complete discussion of CERC gage data analysis, see Thompson (1977).

9. Wave Gage No. 675, located 1420 ft seaward of the landward end of the FRF pier in approximately 20.7 ft of water referenced to mean sea level (msl), was chosen as a reference because it provided the most consistent record during the experiment (i.e., Gage No. 675 failed to obtain measurements at only six hourly intervals, whereas the other gages failed more frequently). Therefore, although the visual observations were recorded 26 times, the data set contains only 20 complete (gage and visual) observations and measurements.

10. The wave height at breaking was computed by the linear wave theory shoaling equation, with the breaking depth given by

$$H_b = 0.78d_b \quad (1)$$

where

H_b = breaking wave height

d_b = water depth at breaking

Refraction was not considered in the wave height transformation.

11. As mentioned above, the significant wave period for the gage records was defined as the period associated with the frequency at the middle of the spectral band with maximum energy. Visual observations of period were determined by timing 11 wave crests passing a stationary point and then dividing by ten. Timing started when the first crest passed the point and ended when the eleventh crest passed.

Wave Angle at Breaking

12. The wave angle at breaking was determined from the aforementioned radar system. The system included a Raytheon 1020/9XR Mariners Pathfinder X-band radar with a pulse width of 0.05 microsecond, a range resolution of 10-20 m (32.8-65.6 ft), and a 2.74-m (9-ft) slotted array antenna with a horizontal beam width of 0.9 degree at 3 db and rotation at 33 rpm. Pulses of electromagnetic energy with a nominal wavelength of 3 cm and a nominal frequency of 10^{10} hertz are beamed over the water, and part of the energy is backscattered to the antenna (for a complete discussion, see Mattie and Harris (1979)). Nine pictures were taken of the radar scan each hour. Later, the data were reduced by measuring the nine wave angles from each hourly set of photographs and averaging to the nearest degree. Visual observations of wave angle were estimated to the nearest degree by the six observers using the protractor provided on the back of the standard LEO form (Figure 4). A wave ray approaching perpendicular to the shoreline was recorded as having a 90-degree wave angle; a wave approaching from the right of a normal to the beach for an observer looking seaward was considered to have a wave angle greater than 90 degrees; while waves approaching left of the normal were considered smaller than 90 degrees.

Foreshore Slope

13. The slope of the wetted beach face was measured by the LEO observers with clinometers. Because the clinometer is itself an instrument, no additional "truth" data were taken. Observations of slope measurements were compared among observers to obtain "confidence intervals"; the use of confidence intervals assures that slope varies with location rather than among different observers.

Width of the Surf Zone

14. LEO observers estimated the distance from the wetted limit of the shoreline to the breaking waves; hence, these values were simply compared to each other to establish the consistency of observations by different observers. No instrument measurements (truth data) were made of surf zone width.

Longshore Current Parameters

15. Fluorescein dye packets were thrown into the surf zone by LEO observers to estimate the longshore current. The following three separate measurements were taken:

- a. The estimated distance in feet from the shoreline to the point of dye injection.
- b. The distance the dye patch travelled in a 60-second period as paced off along the shoreline by the observer.
- c. The direction the dye travelled (positive is defined as movement to the right when looking seaward).

16. Since the magnitude of the longshore current velocity varies with distance from shore across the surf zone, each observation should be reduced to a common basis in order to compare one longshore current observation with another. In an attempt to do this, the theoretical longshore current velocity distribution of Longuet-Higgins (1970) (for a plane beach) was used. According to Longuet-Higgins, for a value of his mixing parameter P of 0.4

$$V = \begin{cases} (10/49)X - (5/7)X \ln X & 0 \le X < 1 \\ (10/49)X^{-5/2} & 1 \le X < \infty \end{cases} \qquad (2)$$

where

V = dimensionless current velocity = v/v_o

X = dimensionless distance = x/x_b

v = velocity at a distance x into the surf zone

v_o = longshore current velocity at the breaker line if horizontal mixing is neglected

x_b = distance to the breaker line

Equation 2 is valid only when P, the dimensionless mixing parameter which expresses the relative importance of horizontal mixing in transferring momentum, is taken to be 0.4. Other values of P lead to more complex relationships, but $P = 0.4$ appears to be an upper limit to observations of the longshore current distributions. All the values needed to solve Equation 2 are available in the LEO data set except for the value of v_o which can be considered a reference current velocity. Equation 2 was solved for v_o for each LEO observation, and these calculated reference longshore currents were compared.

17. It was discovered that the distribution of velocity could not be used to normalize the observations because of inaccuracies in estimating either surf zone width or the distance from shoreline to point of dye injection; in several instances, the surf zone width had been estimated to be only a fraction of the distance from the shoreline to where the dye packet was thrown, resulting in unrealistic values for v_o. Therefore, direct comparison between the LEO current observations was made without correcting for location in the surf zone. At the time of the experiment there were no current meters operating at the FRF pier.

Wave Type

18. The type of breaking wave was assigned a number and recorded as follows:

a. 0 (calm).

b. 1 (spilling).

c. 2 (plunging).

d. 3 (surging).

e. 4 (spill/plunge (transition between spilling and plunging)).

Table A1, Appendix A, shows the variation of breaker types observed during the experiment.

Wind Speed and Direction

19. As with wave type, wind speed and direction as recorded in the LEO program are not suited to an analysis which calculates mean, standard deviation, and confidence intervals. These parameters are vectors, and their direction is given by compass sector. Wind speeds could have been handled separately; however, it is the combined effect of direction and speed that is important. Therefore, no statistical analysis of these data was performed; wind speed and direction data are presented in Table A2, Appendix A.

PART IV: METHODS OF ANALYSIS

20. The statistical analyses were performed using standard equations as discussed below. Out of a possible total number of 1248 LEO data entries, excluding wave type and wind speed/direction data, ten data entries were not reported. These missing data values were estimated as being equal to the average of the remaining observations for the same variable taken that hour; thus an error, although small, was introduced. As mentioned in paragraph 9, six wave gage readings were not obtained during the experiment due to equipment failure; therefore, only 20 complete data sets (observations versus wave measurements) were analyzed.

Mean and Standard Deviation

21. The mean and standard deviations were calculated using the two following equations, respectively (see Benjamin and Cornell 1970):

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \tag{3}$$

$$s = \sqrt{\frac{1}{(n-1)} \sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{4}$$

where

$\bar{x}$ = sample mean

s = sample standard deviation, unbiased estimator

n = number of observations in the sample

x_i = value of the i^{th} observation

Correlation Coefficients

22. Correlation coefficients were computed by using the following formula (see Benjamin and Cornell 1970):

$$r_{x,y} = \frac{1}{n} \sum_{i=1}^{n} \left(\frac{x_i - \bar{x}}{s_x} \right) \left(\frac{y_i - \bar{y}}{s_y} \right) \tag{5}$$

where

$r_{x,y}$ = the correlation coefficient between variables x and y

x_i and y_i = the i^{th} observation of the variables x and y

s_x and s_y = the biased standard deviations of the x and y variables, respectively

$\bar{x}$ and $\bar{y}$ = the means of the samples

n = the number of observations

The correlation coefficient $r_{x,y}$ is a measure of how well two variables are linearly correlated. The relationship between the LEO observations and corresponding gage/radar measurements should be linear, and the correlation coefficient should approach 1.0. If the variables are uncorrelated, $r_{x,y}$ should approach 0.0, while for negatively correlated variables $r_{x,y}$ should approach -1.0.

Confidence Intervals

23. Confidence intervals were computed using the t-statistic because the sample size was small and the uncertainty associated with not knowing the population variance could not be ignored. The t-statistic distribution is broader than the normal distribution and reflects the greater uncertainty introduced because a good estimate of the standard deviation is not available. The following equation was used (see Benjamin and Cornell 1970):

$$P \left\{ \left[\bar{x} - \frac{t_{(\alpha/2,n-1)} s}{\sqrt{n}} \right] < m < \left[\bar{x} + \frac{t_{(\alpha/2,n-1)} s}{\sqrt{n}} \right] \right\} = 1 - \alpha \tag{6}$$

where

P = probability

$(1 - \alpha)$ = desired confidence band

s = standard deviation of the sample

$t_{(\alpha/2,n-1)}$ = t-statistic with $n-1$ degrees of freedom

m = population mean

$\bar{x}$ = sample mean (Equation 2)

n = number of observations in the sample

Equation 6 states that the probability that the population mean is between the limits given by the terms in brackets is $(1 - \alpha)$. Or stated another way, for the desired level of probability that the population mean is included between two limits, the confidence band must be made as wide as indicated by the term in brackets. In all of the analyses of confidence intervals herein, a value of 0.95 was used for $(1 - \alpha)$. The confidence intervals listed in this report are the values of interval width on each side of the sample mean.

24. Narrower confidence estimates can be established with larger data sets (i.e., as n increases, the band required for the same level of confidence decreases). An ideal version of this experiment would have involved 200 observers, each taking simultaneous observations; in lieu of this ideal, six observers took measurements spread over a period of time. A least squares regression line was then fitted to both upper and lower confidence limits. The slope, y-intercept, and R^2 values found in Table A3 were computed from Equations 7, 8, and 9 (Draper and Smith 1966), respectively:

$$b_1 = \frac{\sum_{i=1}^{n} x_i y_i - \left[\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)\right]/n}{\sum_{i=1}^{n} (x_i)^2 - \left[\left(\sum_{i=1}^{n} x_i\right)^2\right]/n} \tag{7}$$

$$b_o = \frac{\sum_{i=1}^{n} (y_i) - (b_1)\left(\sum_{i=1}^{n} x_i\right)}{n} \tag{8}$$

$$R^2 = SS_{reg}/SS_{mean} \tag{9}$$

where

- x and y = ordinate and abscissa values, respectively
- b_1 = slope of the regression line
- b_o = y-intercept of the regression line
- R^2 = proportion of total variation about the mean explained by the regression
- SS_{reg} = sum of squares due to regression
- SS_{mean} = sum of squares about the mean

The SS_{mean} is simply $\sum (y_i - \bar{y})^2$, where $\bar{y}$ is the mean. SS_{reg} is $\sum (\hat{y}_i - \bar{y})^2$ where $\hat{y}_i$ is the value predicted by the regression line. If the regression line is a good representation of the upper or lower limits of the confidence bounds (i.e., if the regression line is a good predictor), SS_{reg} approaches SS_{mean} and R^2 approaches 1.0; the smaller R^2 gets, the more scatter and the worse a predictor the regression line is. R^2 therefore gave some insight into how variable the confidence bands were for each of the 20 observations.

25. Another method used to obtain confidence intervals involved plotting the observations of the six observers for each hour of the test against the mean of the six observations and also against the value measured by the gage. This method of graphing the "spread" of the data is discussed further in Part V.

26. Because the assumption that observations are distributed according to a normal distribution is required to determine confidence intervals, the ratio of confidence interval width to standard deviation is a constant.

PART V: RESULTS

27. This part summarizes and discusses the results of the statistical analyses. Individual observed variables will be discussed separately. Because of the limited scope of the experiment, the various statistics generated by the analyses should not to be interpreted as representative of all LEO data. Several similar or broader experiments are needed to better quantify the variability of visual wave observations. The observers themselves were variables. The six persons who participated in this experiment could have been better or worse than the "average" field observer retained for LEO data gathering. It is not known whether LEO observers improve with experience or whether they continue to hold any biases they may have had at the start of their observation experience. The observers in this experiment were not typical observers since they were pressed into service for this experiment alone, and they may thus have exhibited biases that would not have persisted had they been continuing observers.

Wave Period

28. Table 1 lists the means, standard deviations, and confidence intervals for wave period, wave height at breaking, wave angle at breaking, foreshore slope, surf zone width, and longshore current velocity. During the experiment, the gage recorded significant wave periods between 8 and 11 seconds. The means of the LEO observations fell in the same range; however, the average width of the confidence intervals was ± 3.42 seconds (the average width of the confidence intervals from the 20 data sets was considered to be an estimate of the overall confidence interval). The 95 percent confidence limits on wave period were, therefore, 9.5 ± 3.42 seconds (i.e., 6.1-12.9 seconds). Note that the upper limit is more than twice the lower limit, a variation due largely to variations in the observers' decisions on what constitutes a wave. Did observers include a wave which had previously broken? Did they count only the larger waves? If an observer saw larger waves breaking farther offshore and chose an imaginary point past which to count 11 wave crests, wave periods would certainly turn out to be longer because the smaller waves were not counted, giving bias to the longer period waves. Whether or not the observer counted a small perturbation on a larger irregular wave would alter the

Table 1

Mean, Standard Deviation, and Confidence Intervals of the Observers

Parameter	Observation No.	Mean	Standard Deviation	Confidence Interval
Wave period (sec)	1	8.650	3.316	3.481
	2	8.900	3.562	3.739
	3	10.167	3.445	3.616
	4	10.533	3.419	3.588
	5	9.350	4.261	4.473
	6	9.767	2.395	2.514
	7	9.433	2.406	2.525
	8	9.250	2.898	3.042
	9	8.600	3.020	3.170
	10	9.433	3.173	3.330
	11	10.417	1.315	1.380
	12	9.200	3.127	3.282
	13	8.867	3.064	3.216
	14	8.767	2.785	2.923
	15	9.667	3.777	3.964
	16	10.217	4.345	4.561
	17	10.117	3.636	3.816
	18	10.233	3.330	3.495
	19	9.033	3.327	3.492
	20	10.467	4.594	4.822
	Average	9.5	3.26	3.42
Wave height (ft)	1	2.067	0.327	0.343
	2	2.250	0.536	0.562
	3	2.483	0.688	0.722
	4	2.183	0.591	0.621
	5	2.650	0.622	0.653
	6	1.850	0.586	0.615
	7	2.100	0.704	0.739
	8	1.967	0.794	0.834
	9	2.200	0.660	0.693
	10	2.383	0.794	0.833
	11	2.683	0.875	0.918
	12	2.700	1.175	1.233
	13	3.500	1.305	1.370
	14	2.967	1.294	1.358
	15	3.100	0.974	1.022
	16	2.483	0.431	0.452
	17	2.233	0.361	0.379
	18	2.133	0.266	0.279
	19	2.517	0.553	0.580
	20	2.367	0.589	0.618
	Average	2.4	0.71	0.74

(Continued)

Table 1 (Continued)

Parameter	Observation No.	Mean	Standard Deviation	Confidence Interval
Wave angle (deg)	1	103.333	9.309	9.771
	2	104.833	8.612	9.039
	3	104.333	9.933	10.426
	4	101.333	8.238	8.647
	5	105.667	10.172	10.676
	6	105.500	11.113	11.664
	7	105.000	9.252	9.711
	8	105.667	9.606	10.082
	9	105.833	11.143	11.696
	10	103.833	8.353	8.767
	11	104.667	11.518	12.089
	12	103.500	9.072	9.522
	13	105.500	9.670	10.149
	14	102.667	8.641	9.070
	15	101.833	13.497	14.166
	16	100.667	9.626	10.104
	17	103.333	11.622	12.198
	18	106.667	11.255	11.813
	19	101.333	9.092	9.543
	20	104.000	10.973	11.517
	Average	104.	10.0	10.5
Foreshore slope (deg)	1	4.167	1.722	1.808
	2	10.333	2.733	2.868
	3	12.333	1.366	1.434
	4	12.333	1.033	1.084
	5	10.833	3.545	3.721
	6	4.833	0.753	0.790
	7	2.833	0.753	0.790
	8	3.167	0.983	1.032
	9	3.167	1.169	1.227
	10	3.500	0.837	0.878
	11	6.167	2.563	2.690
	12	8.333	2.251	2.363
	13	11.500	1.225	1.286
	14	11.500	1.225	1.286
	15	10.000	2.191	2.300
	16	7.333	0.516	0.542
	17	4.500	0.548	0.575
	18	2.833	0.408	0.429
	19	2.000	0.632	0.664
	20	2.500	0.548	0.575
	Average		1.4	1.4

(Continued)

Table 1 (Concluded)

Parameter	Observation No.	Mean	Standard Deviation	Confidence Interval
Width of surf zone (ft)	1	115.833	36.312	38.113
	2	109.167	65.758	69.020
	3	56.000	27.276	28.629
	4	77.500	54.475	57.177
	5	111.667	61.698	64.759
	6	85.000	38.471	40.379
	7	87.333	19.054	20.000
	8	99.167	33.826	35.503
	9	88.333	16.633	17.458
	10	104.667	39.429	41.385
	11	110.000	48.990	51.420
	12	88.333	28.402	29.811
	13	74.167	20.837	21.870
	14	55.833	29.226	30.676
	15	74.500	36.215	38.011
	16	94.167	66.740	70.050
	17	91.667	33.267	34.917
	18	98.000	19.131	20.080
	19	122.500	73.263	76.898
	20	135.000	65.879	69.147
	Average	94.	40.7	42.8
Longshore current velocity (ft/sec)	1	-0.808	0.304	0.319
	2	-1.125	0.614	0.645
	3	-0.897	0.343	0.360
	4	-0.967	0.366	0.384
	5	-0.978	0.388	0.407
	6	-0.356	0.144	0.152
	7	-0.439	0.366	0.384
	8	-0.517	0.558	0.586
	9	-0.475	0.517	0.543
	10	-0.450	0.445	0.467
	11	-0.617	0.159	0.167
	12	-0.878	0.361	0.379
	13	-0.781	0.399	0.418
	14	-0.494	0.349	0.367
	15	-0.800	0.352	0.370
	16	0.114	0.658	0.691
	17	-0.506	0.409	0.429
	18	-0.869	0.584	0.613
	19	-0.497	0.654	0.686
	20	-0.808	0.327	0.343
	Average		0.42	0.44

period; also, whether the observer counted the short-crested wave, or merely the long-crested waves, is another factor contributing to the variation in observer-determined wave periods. Another factor is the occurrence of bimodal spectra; for instance, observers may only have included waves coming from one of two predominant directions. (This is also a factor in determining gage-measured periods because the wave period assigned to a wave record is the period of maximum density energy, irrespective of direction. Bimodal spectra do not provide an average period, such as an observer tends to see, but rather the period of maximum energy density.)

29. Although confidence intervals provide a range of values within which a given observer can be expected to estimate a parameter, a more important factor is how the individual observations correlate with the actual wave period. As mentioned above, the gage-measured period was also subject to ambiguity in the case of bimodal spectra. Characterizing the waves by a monochromatic wave period when in reality an irregular sea exists can lead to questionable results. Neglecting this, LEO observations were correlated with wave gage significant periods chosen at the middle of the frequency band with maximum energy, regardless of whether the spectra were bimodal. The correlations between observed conditions and (a) the gage/radar-determined values and (b) the mean of the observers are listed in Table 2. Correlation coefficients approach ± 1 if the pairs of values lie along a straight line with the sign of the coefficient depending on the slope of the line. If an observer's values correlate well with gage values, positive values near 1.0 will be computed; if larger than average observations occur with smaller than average gage measurements (and vice versa), negative values of the correlation coefficient result.

30. For this experiment, poor correlation between observations and measured values resulted. The discrepancies between observations and observation means with gage values cannot be attributed to observational errors alone. Variations occur because of the difficulty of deciding what constitutes a wave and when to count a disturbance as a wave; problems are also caused by the somewhat arbitrary method of obtaining a significant wave period from gage measurements. All of these contribute to the sizeable differences between observed and measured wave periods.

31. Appendix B presents plots of each observation versus the observer-mean; Figure 5 plots observation versus gage/radar values. An observer

Table 2

Correlation Coefficients

	Observer No.	Observer vs Observer Mean	Observer vs Gage
Wave period	1	0.335	0.414
	2	0.571	-0.045
	3	-0.068	0.189
	4	0.639	-0.021
	5	0.220	-0.132
	6	0.281	0.188
Wave height at breaking	1	0.881	-0.217
	2	0.551	0.049
	3	0.515	0.018
	4	0.781	-0.332
	5	0.467	0.398
	6	0.611	0.424
Wave angle at breaking	1	0.642	-0.503
	2	0.550	-0.240
	3	0.155	0.317
	4	0.040	0.235
	5	0.141	-0.291
	6	0.168	0.100
Foreshore slope	1	0.953	
	2	0.854	
	3	0.971	
	4	0.912	
	5	0.976	
	6	0.960	
Width of surf zone	1	0.761	
	2	0.342	
	3	0.248	
	4	0.431	
	5	0.689	
	6	0.564	
Longshore current velocity	1	0.610	
	2	0.675	
	3	0.613	
	4	0.595	
	5	0.811	
	6	0.488	

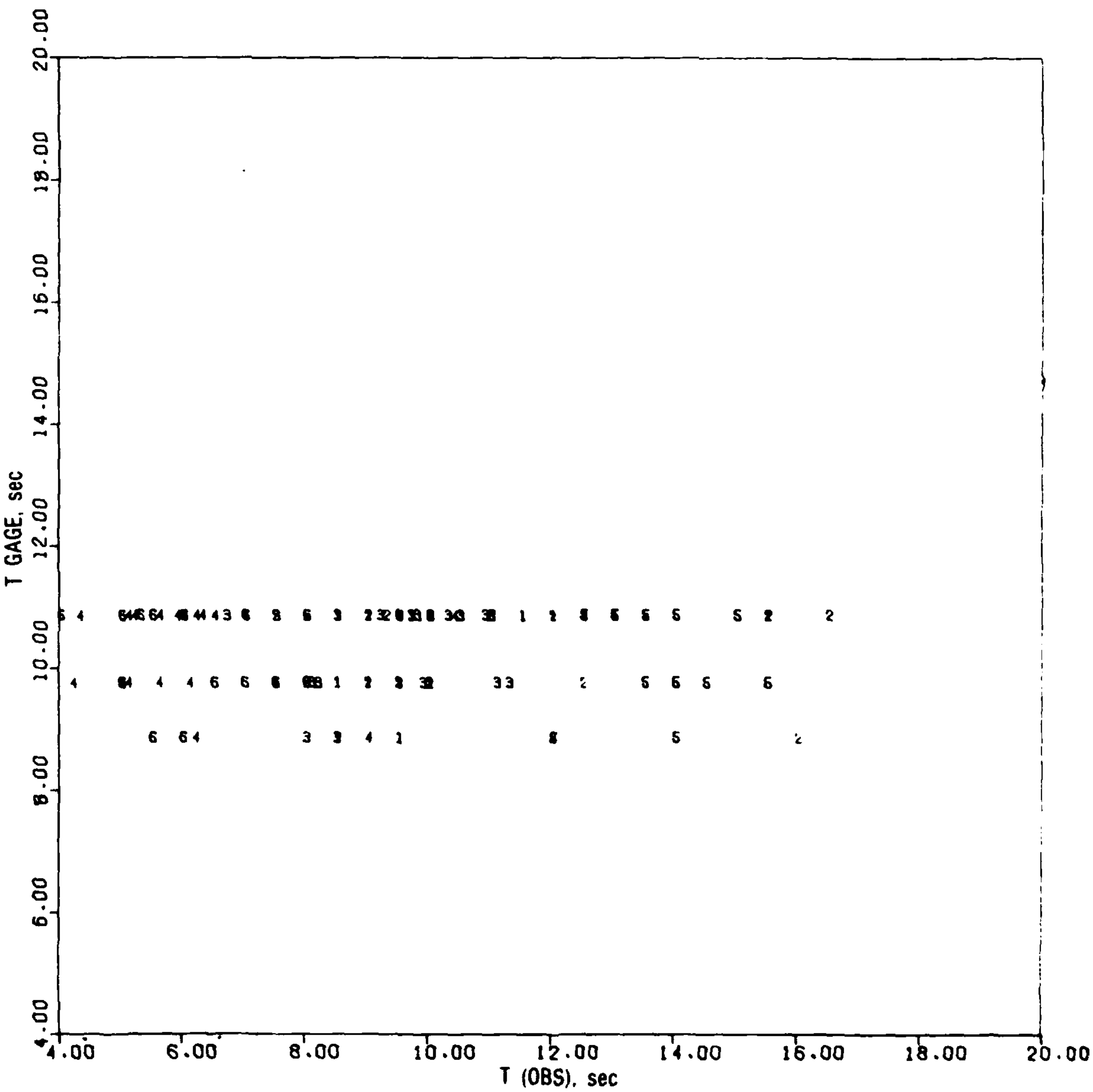


Figure 5. Observed wave period versus measured wave period

bias can be detected from observation of these plots (the plotted number represents the observer who made the estimate). Figure 5 shows that Observer 5's estimates were generally larger than gage values, while observers 4 and 6 usually gave estimates that were smaller than gage values; this suggests the possibility of "calibrating" an observer so that his observations could on the average be corrected to provide a fair estimate of gage values. On the other hand, how could observers, such as 1, 2, and 3, who sometimes overestimate and sometimes underestimate the gage values, be calibrated?

Wave Height

32. The confidence interval for wave height estimation among observers was computed to be ± 0.74 ft (Table 1). Average wave conditions during the experiment were approximately 1-3 ft. Correlation coefficients between observer and gage were again low. Observer 6 was closest to the gage measurements with a correlation coefficient of 0.42; Observer 4 was the worst with $r = 0.33$. Correlation between observations and the observation mean was fair (Figure B2), suggesting that visual observations of wave height may be difficult to estimate accurately, but observers may have consistently estimated incorrectly as a group. Also, the range of wave heights encountered during the experiment was small, which may account for some of the scatter. Figure 6 shows that agreement between observations and gage measurements of transformed significant wave height was poor. Recall that only a shoaling transformation was performed, with refraction and energy dissipation ignored..

33. To determine whether the average of the observed wave heights would provide a better estimate of the gage wave heights, the correlation coefficient was calculated. A value of $r = -0.034$ was obtained, indicating that the average wave height of several observers provided an extremely poor estimate of gage heights.

Wave Angle

34. The average 95 percent confidence interval for wave angle at breaking was ± 10.5 degrees in this study (Table 1). Correlation between observed angle and the radar-determined mean angle was poor. Figure 7 shows that observers were more consistently biased in estimating angle than in estimating

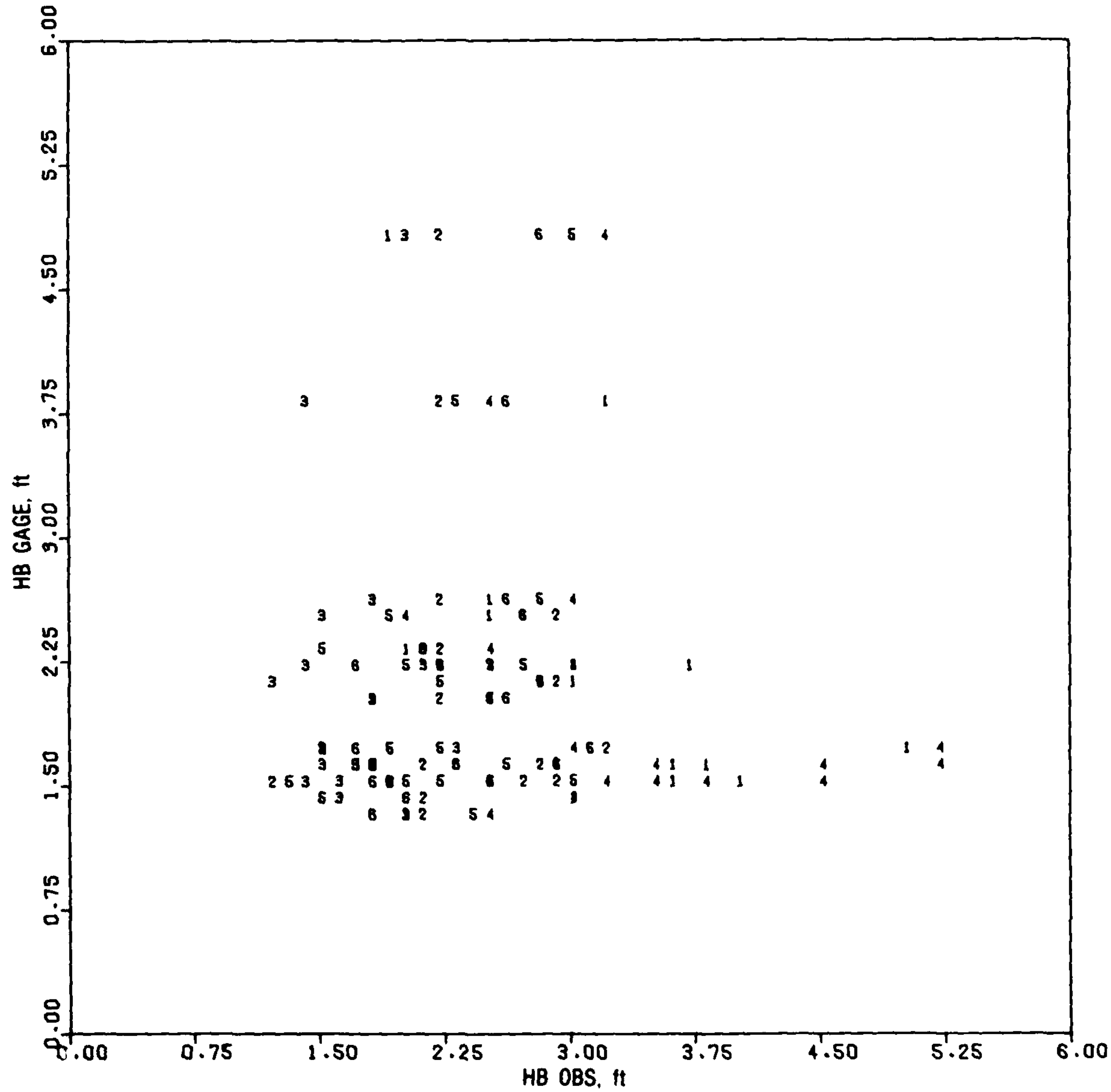


Figure 6. Observed wave height versus measured wave height

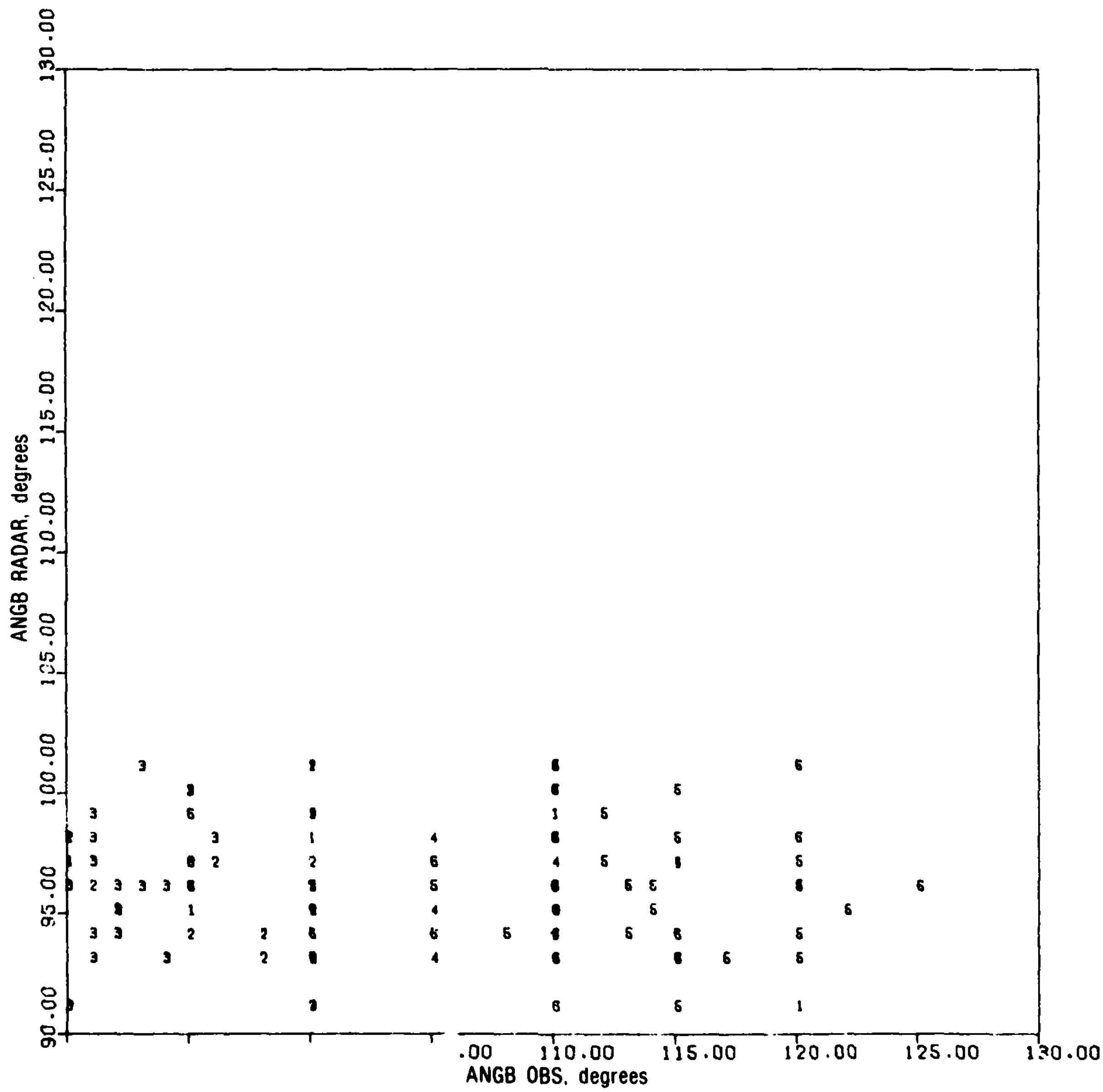


Figure 7. Observed wave angle versus radar-measured wave angle

wave height or period, usually estimating larger wave angles than those which actually occurred. Radar images for a given hourly measurement had a maximum variation in wave angle at breaking of approximately ±5 degrees. This arithmetic average of a number of radar images was compared with the LEO observations.

Foreshore Slope

35. Foreshore slope was measured using a hand level as a clinometer; therefore, there was little possibility of an error in measurement. The difference between two concurrent observations was rather due to the variability of beach foreshore slope and the fact that observers placed the clinometer at different places on the beach. The statistical analyses, therefore, give the range of foreshore slope variability on a given beach. The average of the standard deviations was ±1.4 degrees (Table 1) (note that slope is recorded on the LEO form to the nearest degree). Correlation between observers and the mean of the observations was very good. The values of the correlation coefficient ranged from 0.854 to 0.976, indicating that foreshore slope is the most consistent and probably the most accurate of the data collected in the LEO program. If beach cusps had been present, greater spatial variability would have existed in the beach slopes, and therefore lower correlation coefficients might have been expected. Further demonstration of the quality of the foreshore slope data is shown in Figure 8 which plots foreshore slope versus tidal elevation. The data clearly show that as the tidal elevation increased, foreshore slope also increased. This was as expected since for an equilibrium beach profile (see, for example, Dean (1977)) the profile should be steeper at the mean high water line.

Surf Zone Width

36. The observed surf zone width during the experiment averaged about 94 ft (Table 1). The average of the confidence intervals was ±42.8 ft. The average confidence interval was thus nearly half of the average .alue of the surf zone width estimate--a poor correlation. Correlation coefficients varied from 0.248 to 0.761.

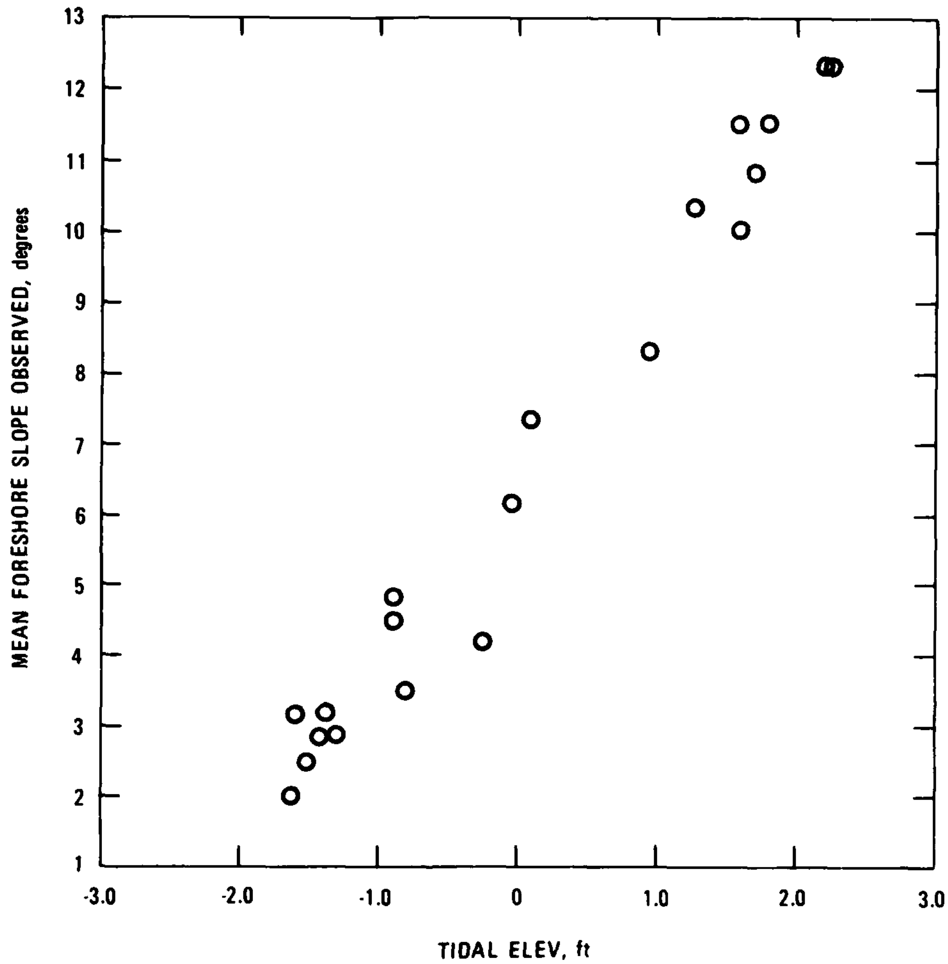


Figure 8. Tidal elevation versus foreshore slope (observer mean)

37. Surf zone width increases as tide level decreases provided the wave height remains fairly constant; this is because the surf zone is on the flatter part of the beach profile. It is possible that the width of the confidence interval will increase as the surf zone width increases. Conversely, a narrower surf zone suggest a smaller estimate error; however, the ratio still produces a large standard deviation and hence a broad confidence band. To test which is correct, tidal elevations were plotted against confidence intervals (Figure C1). The scatter on the graph suggests that neither interpretation is correct.

Longshore Current

38. As mentioned, difficulties were encountered in attempting to rationally compare the observers' longshore current data. The currents were compared directly without correction and neglecting the effects of the offshore distance to the point of current measurement. The average confidence interval was ± 0.44 ft per second (Table 1). Correlation coefficients ranged from 0.488 to 0.811 between observed velocities and the observer mean. Since current measurements along the pier were not made during the experiment, correlation with measured data was not possible.

Wave Type and Wind Speed/Direction

39. The types of waves observed during the experiment are tabulated in Appendix A, Table A1. At no time during the experiment did all six observers agree on the wave type, and only once did five of the six observers agree. Four of the six observers agreed five times. On one-half of the observations, all four wave types were reported. Calm conditions were never reported.

40. Wind speed and direction observations are tabulated in Table A2. As with wave types, at no time did all observers record either the same speed or direction. Ranges of speed and direction are also listed in Table A2. There is a large discrepancy among observers. Twelve times one or more observers recorded calm conditions while other observers recorded some wind. In one case, two observers recorded calm, while other observed recorded speeds between 2 and 6 miles per hour. Only once did five of the six observers recorded identical wind speeds; however, direction varied by as much as

90 degrees. A variation of 180 degrees was the maximum observer variation in wind direction reported.

Possible Improvements

41. The LEO surf observation program is attractive because of its relatively low costs. Improving the quality of the data must be weighed against any increase in the cost of obtaining better quality data. Also, since most observers are unpaid volunteers, changes that increase the amount of time required to obtain a set of data must be carefully considered. Simple instrumentation might possibly be developed that would neither significantly increase cost nor increase the amount of time required to obtain a data set. For example, in areas where coastal structures are present, graduated wave staffs could be installed and used to estimate wave heights. Range finder/stadia type instruments might be developed to measure surf zone width and wave height; however, the cost of such equipment might be prohibitive.

42. The results of the experiment point out some of the limitations of the LEO data and suggest some ways to improve data quality. The importance of carefully training observers and periodically meeting with them in the field to observe their methods is indicated. The data should be reviewed periodically to detect any obvious errors, and feedback to the observers should be provided to correct procedures and to offer encouragement. Ideally, after a few days of data have been obtained by a new observer, these data should be reviewed and the observer informed of the results of the review. He should then be observed taking a set of observations and his data compared with an independent set of data taken by the individual providing the training. Large discrepancies should be brought to his attention and their cause determined. In recruiting observers, individuals with some technical background should be sought since they are more likely to be able to estimate distances, etc.

43. Further evaluation of LEO observations is required to better define the range and cause of errors. Quantifying the variability of LEO data is necessary to establish how much confidence a user can have in the data.

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APPENDIX A: TABLES

Table A1

Wave Type

Observation Number	Observer #1	Observer #2	Observer #3	Observer #4	Observer #5	Observer #6
1	Plunging	Surging	Plunging	*	**	Spilling
2	**	Surging	Spilling	**	**	Spilling
3	Spilling	Plunging	Spilling	Spilling	Spilling	**
4	Spilling	Plunging	**	**	**	**
5	**	Spilling	**	**	**	Spilling
6	Plunging	Surging	Spilling	Spilling	**	Spilling
7	Plunging	Surging	**	Spilling	**	Spilling
8	Plunging	Surging	Spilling	Spilling	**	Spilling
9	Plunging	Plunging	Spilling	Spilling	Plunging	Spilling
10	Plunging	Plunging	Spilling	Spilling	**	**
11	Plunging	Surging	**	Spilling	Plunging	Spilling
12	**	Surging	**	**	**	**
13	Plunging	Plunging	Plunging	**	Plunging	Spilling
14	Plunging	Plunging	**	**	Plunging	Spilling
15	Plunging	Plunging	Plunging	**	Plunging	Spilling
16	Plunging	Surging	Spilling	**	Plunging	**
17	**	Surging	**	**	Plunging	Spilling
18	Plunging	Surging	**	**	Plunging	Spilling
19	**	Surging	Spilling	**	Plunging	Spilling
20	Plunging	Surging	Spilling	**	Plunging	Spilling

* Observation not recorded.
** Spilling and plunging.

Table A2

Wind Speed (mph)/Direction*

Observation Number	Observer #1	Observer #2	Observer #3	Observer #4	Observer #5	Observer #6	Ranges Max-Min/Max-Min
1	7/4	7/4	6/4	6/**	6/**	7/2	7-6/4-2
2	7/4	6/3	7/4	6/**	7/3	7/2	7-6/4-2
3	7/5	6/3	4/4	5/**	6/3	5/2	7-4/5-2
4	6/5	6/3	6/4	7/**	4/3	5/3	7-4/5-3
5	4/4	4/3	6/4	4/**	5/3	4/2	6-4/4-2
6	3/5	3/3	3/4	0/**	0/0	0/0	3-0/5-0
7	5/4	5/4	5/4	5/**	4/3	5/2	5-4/4-2
8	5/6	3/4	3/3	4/**	3/4	3/3	5-3/6-3
9	4/5	4/3	5/5	4/**	4/4	4/3	5-4/5-3
10	4/6	5/3	3/5	3/**	0/0	0/0	5-0/6-0
11	4/7	5/3	0/0	1/**	3/4	0/0	5-0/7-0
12	3/5	5/3	0/0	2/**	3/4	2/2	5-0/5-0
13	4/7	6/3	2/4	2/**	0/0	0/0	6-0/7-0
14	5/6	**/3	0/0	2/**	2/4	0/0	5-0/6-0
15	3/7	1/3	0/0	4/**	2/7	0/0	4-0/7-0
16	3/7	2/7	0/0	2/**	2/7	4/8	4-0/8-0
17	2/7	2/7	0/0	2/**	0/0	0/0	2-0/7-0
18	3/7	3/7	0/0	2/**	0/0	2/8	3-0/8-0
19	2/7	3/7	4/6	0/0	3/3	3/4	4-0/7-0
20	3/5	4/7	0/0	4/**	4/7	4/4	4-0/7-0

* Symbols for direction are defined as follows:
(0 = calm)
1 = N 5 = S
2 = NE 6 = SW
3 = E 7 = W
4 = SE 8 = NW

** Observations not recorded.

Table A3

Least Squares Regression Analysis on the Upper and Lower Confidence Intervals of the Observed Data

	Confidence Interval*	Slope Reg Line	Y-Intercept	R^2**
Wave period	P	0.424	4.055	0.490
	M	0.401	7.093	0.339
Wave height	P	0.576	0.608	0.902
	M	0.954	0.819	0.415
Wave angle	P	0.577	37.850	0.665
	M	0.611	46.844	0.519
Foreshore slope	P	0.860	-0.280	0.967
	M	1.082	0.985	0.947
Width of surf zone	P	0.526	22.091	0.813
	M	0.600	63.244	0.271
Longshore current	P	0.749	-0.491	0.810
	M	0.821	0.240	0.754

* P = upper limit of confidence interval; M = lower limit of confidence interval.

** See Equation 8.

APPENDIX B: PLOTS OF OBSERVATIONS VERSUS OBSERVATION MEANS

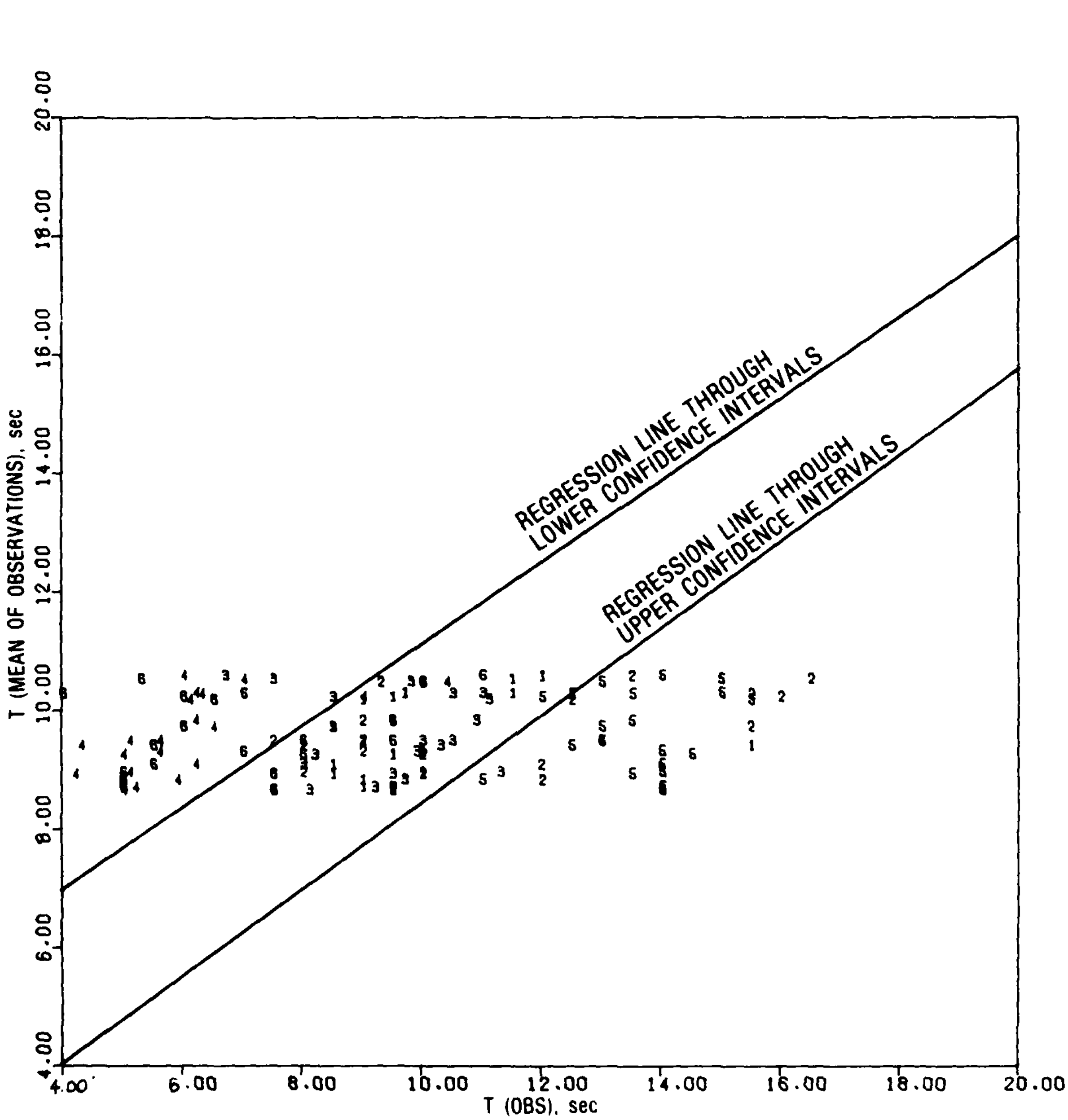

Figure B1. Observed wave periods versus mean of wave period observations

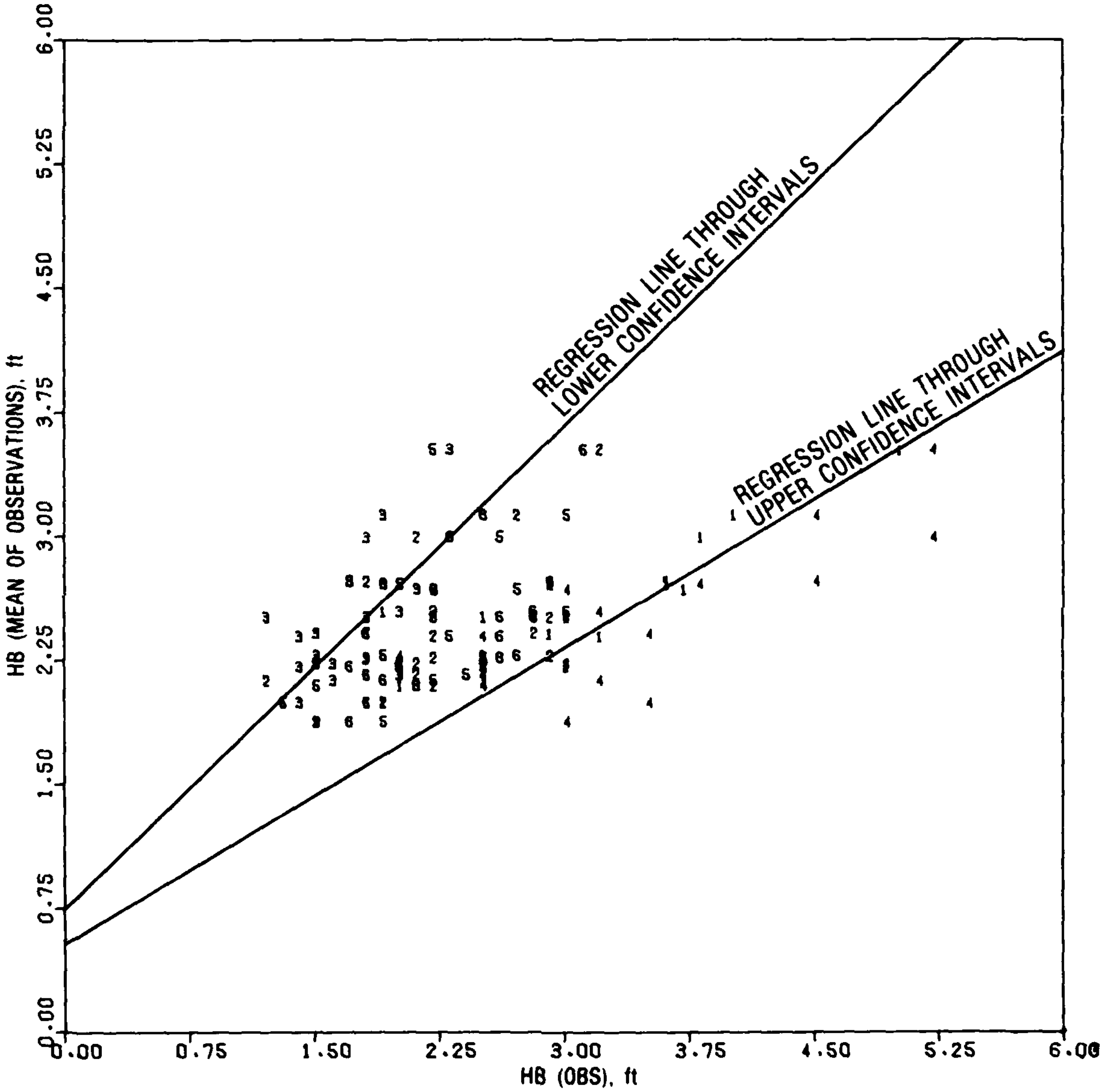

Figure B2. Observed wave heights versus mean of wave height observations

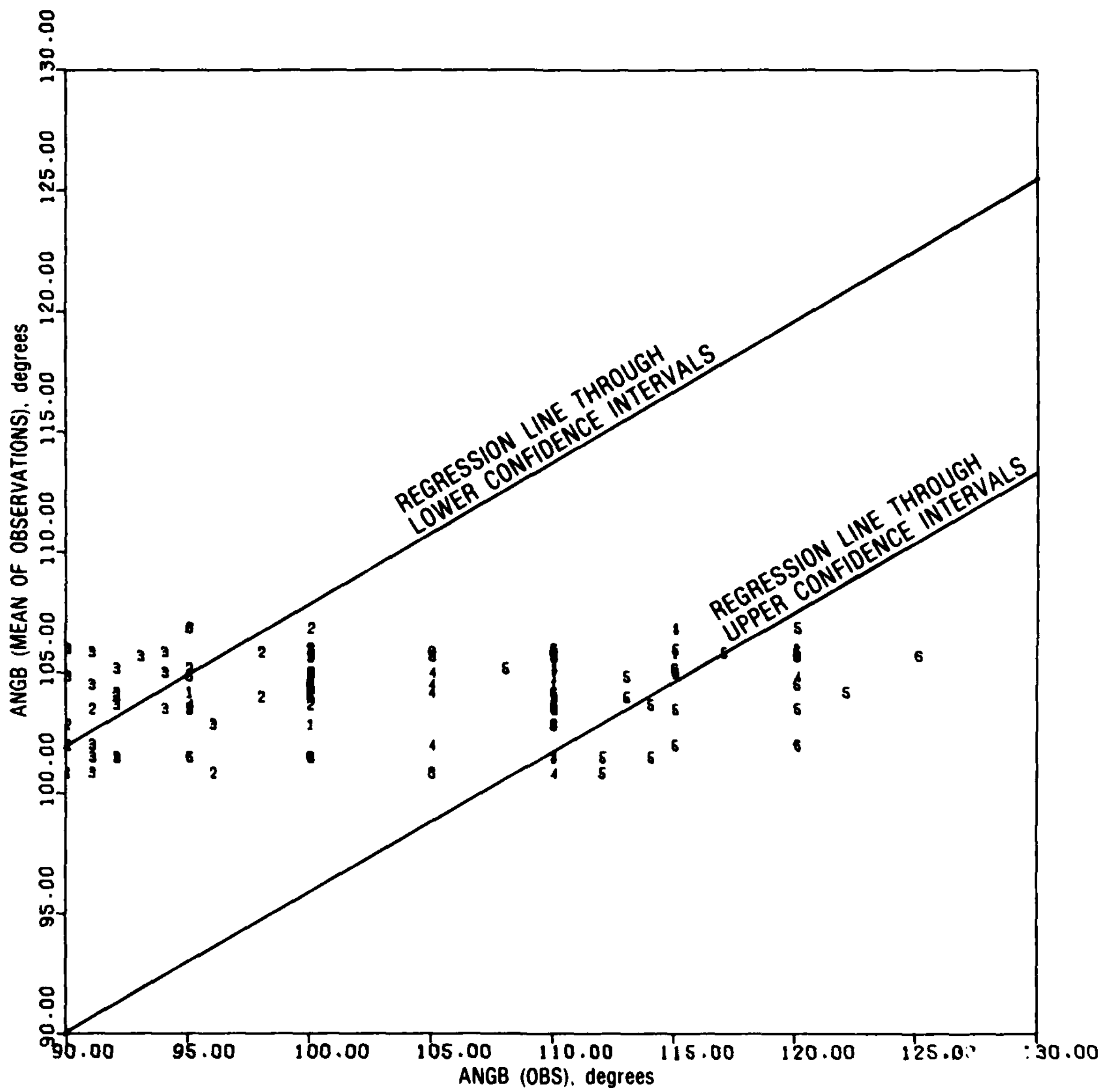

Figure B3. Observations of wave angle versus mean of wave angle observations

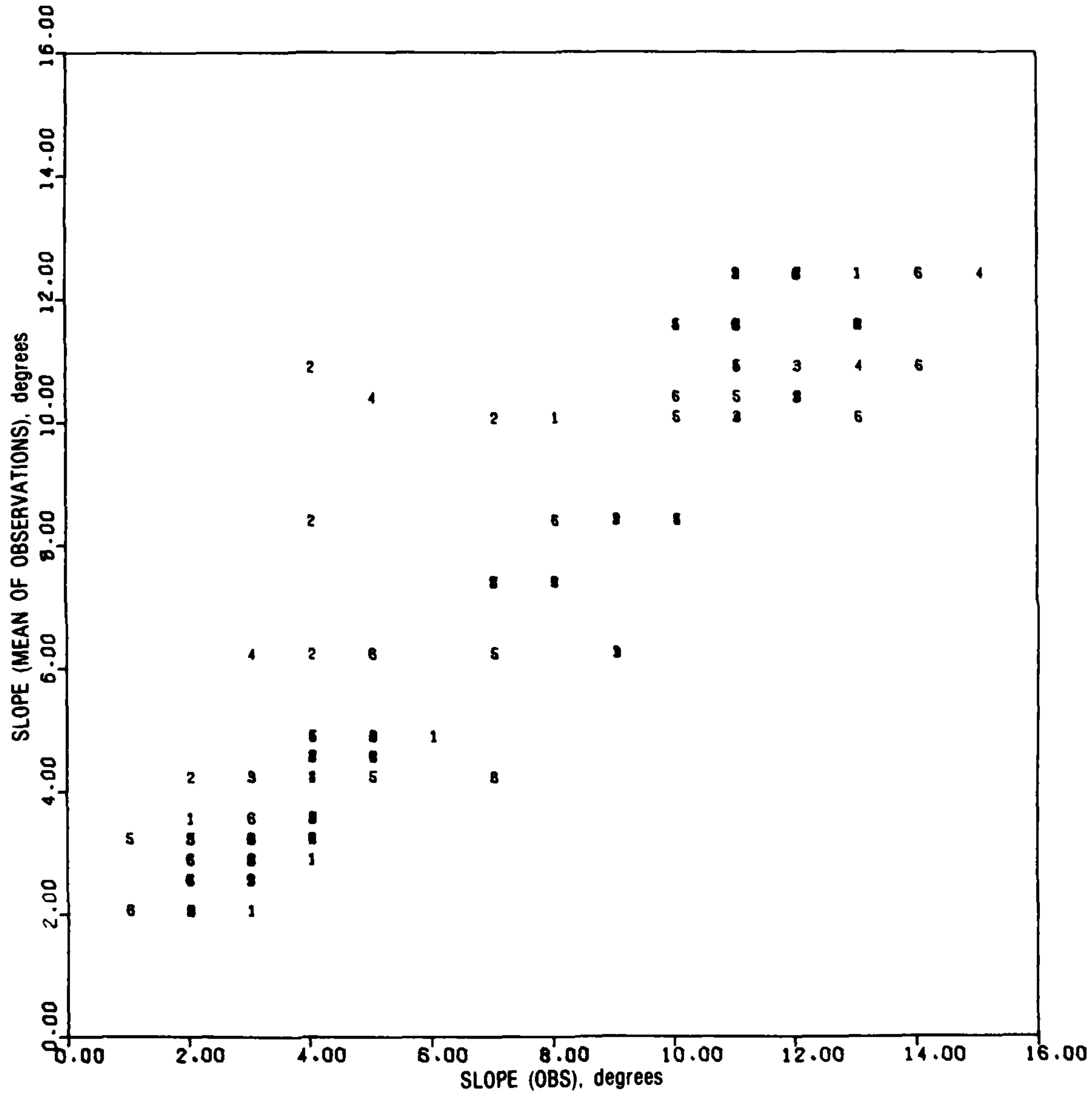

Figure B4. Observations of foreshore slope versus mean of foreshore slope observations

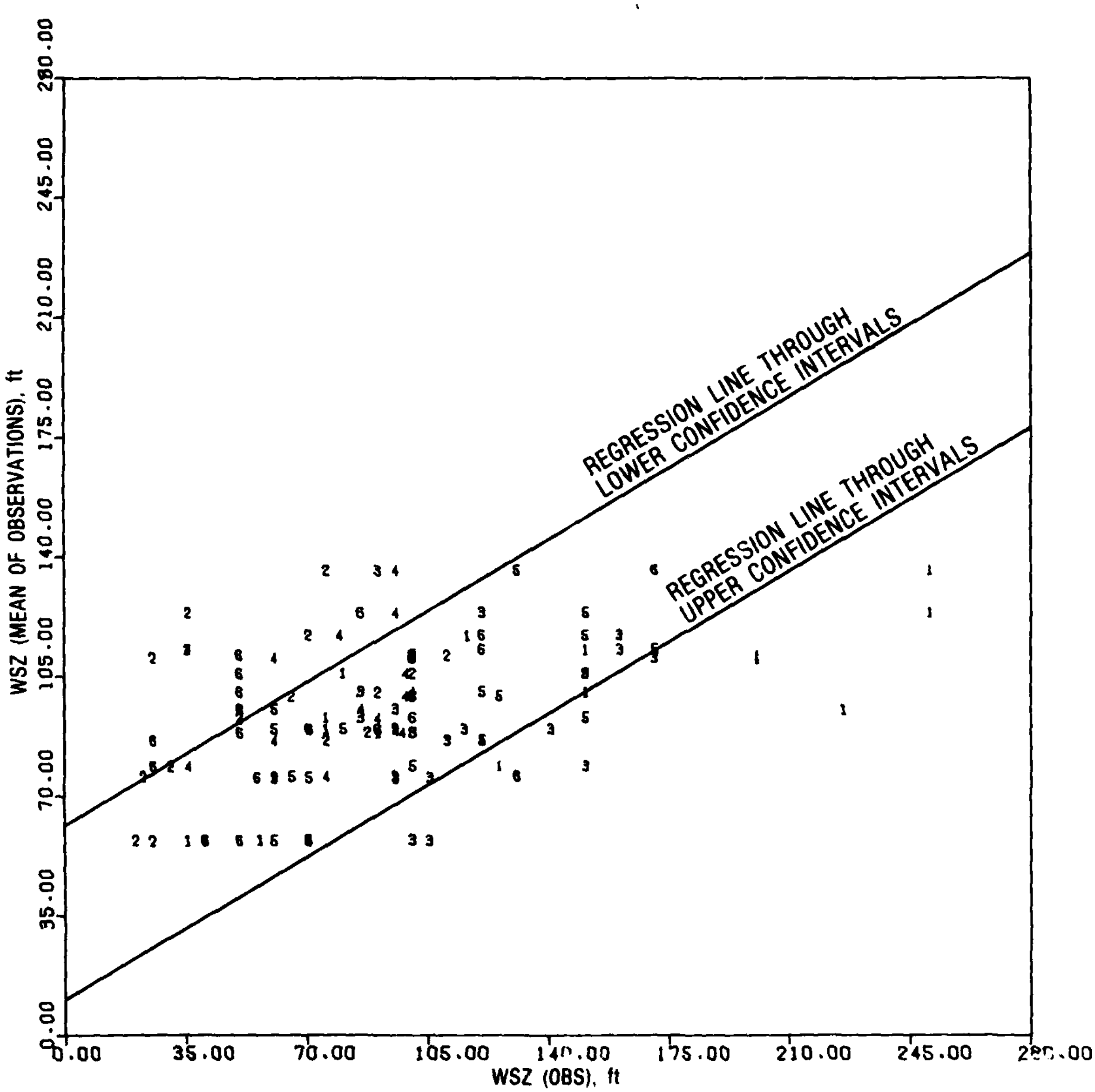

Figure B5. Observations of surf zone width versus mean of surf zone width observations

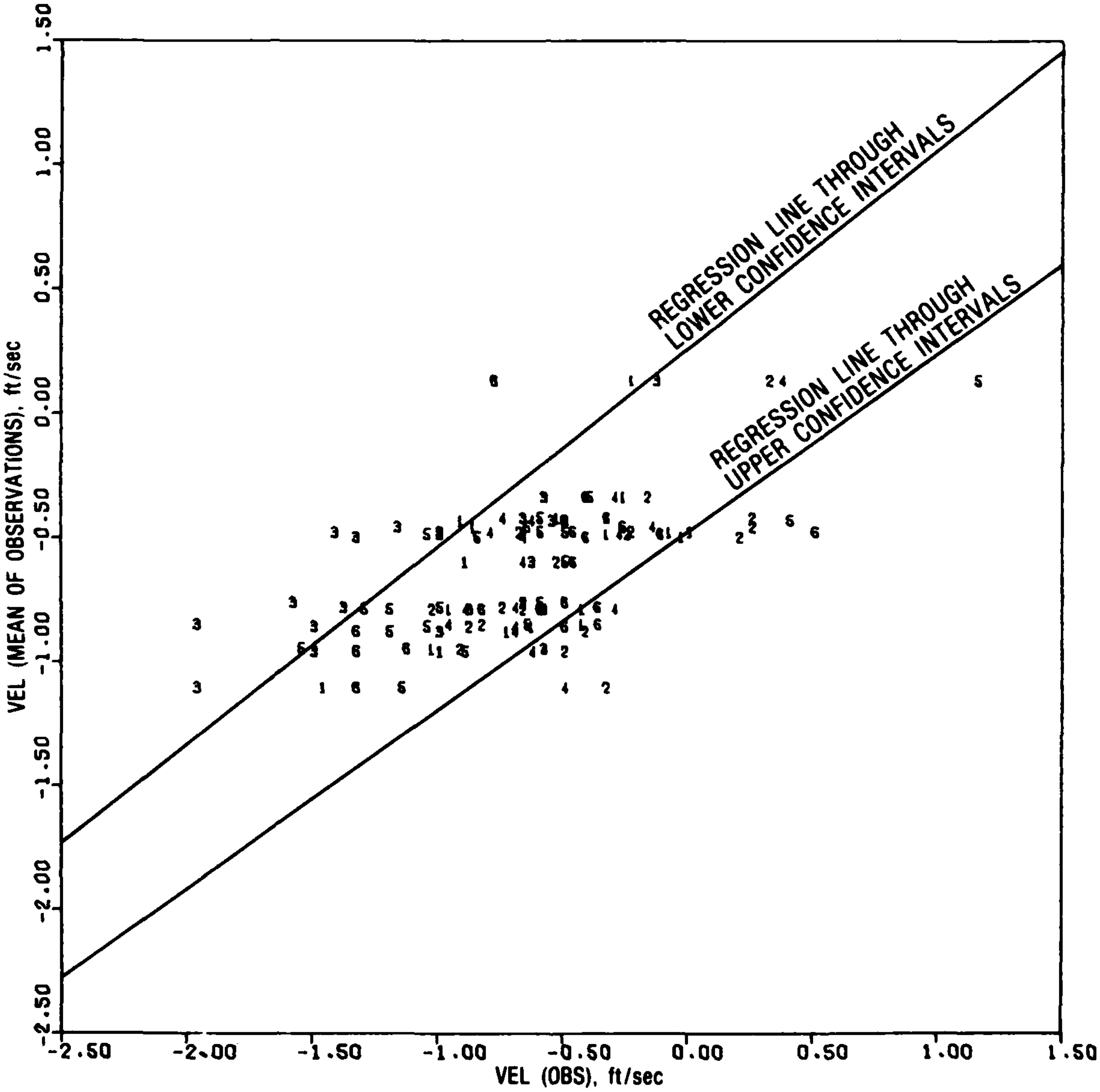

Figure B6. Observations of longshore current velocity versus mean of longshore current observations

APPENDIX C: ACTUAL TIDE VERSUS SURF ZONE WIDTH AND PREDICTED TIDAL CURVE

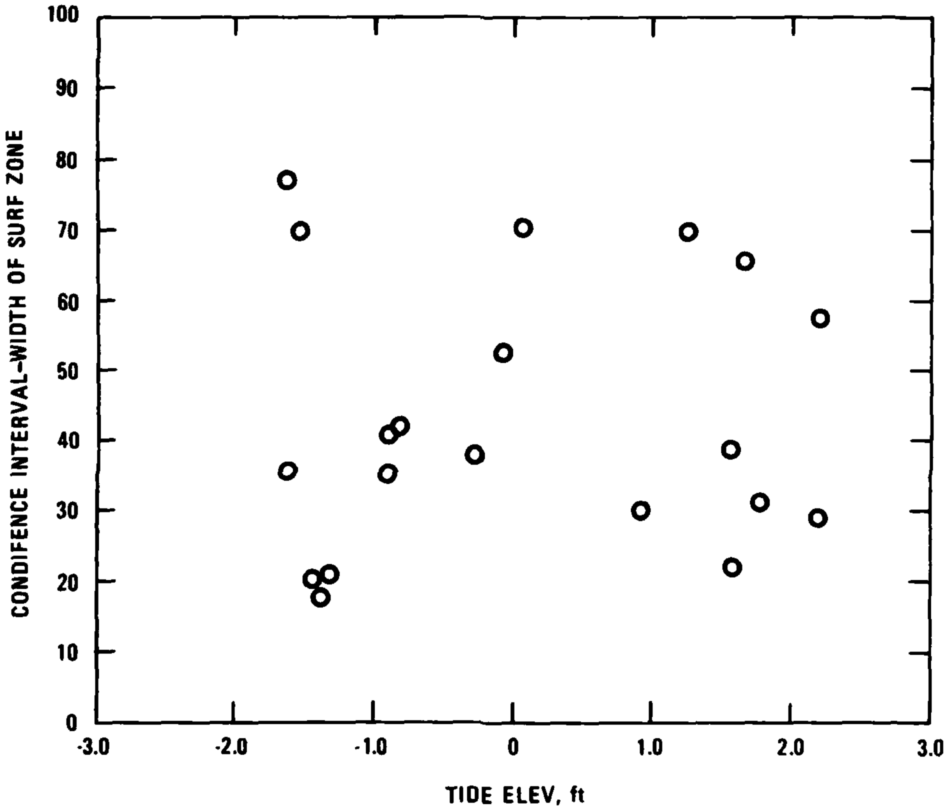

Figure C1. Actual tide versus confidence intervals for surf zone width

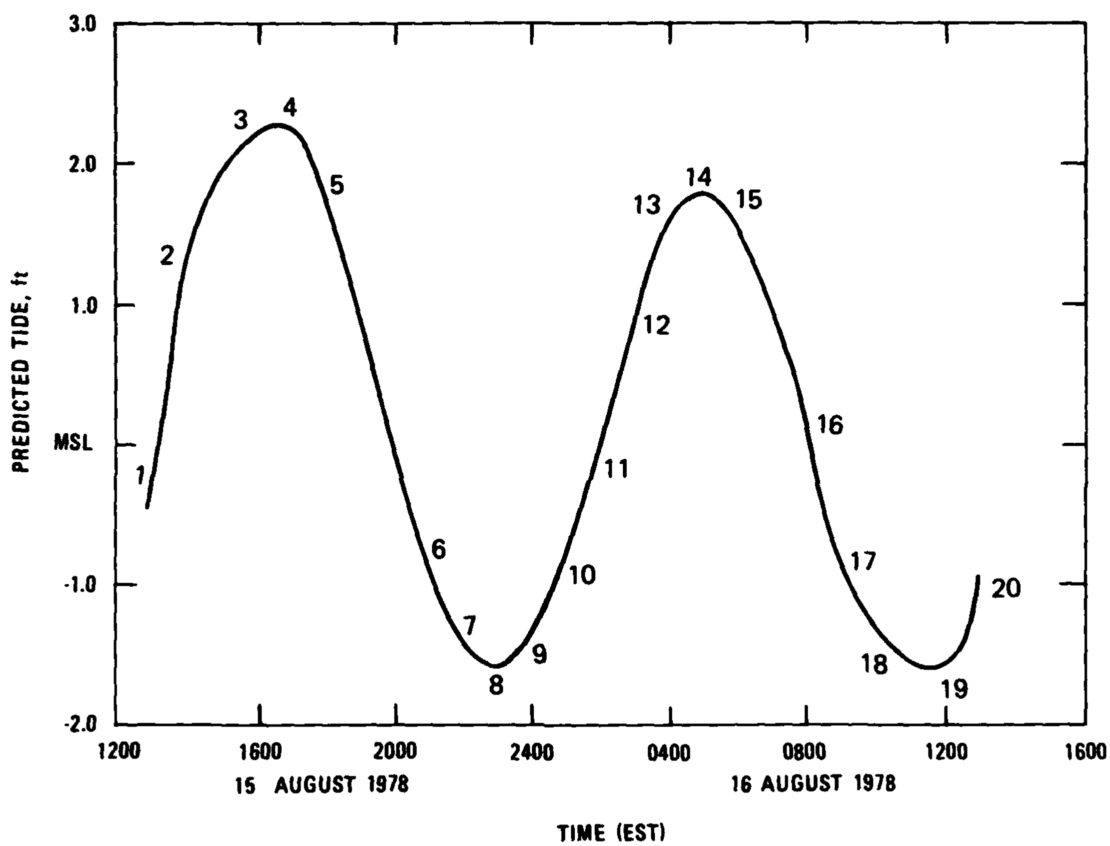

Figure C2. Predicted ocean tide for Kitty Hawk, North Carolina